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Rainfall Runoff Model Evaluation for Lebir River, Kelantan, Malaysia

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B Winarta[1], P T Juwono[1] and N A A Ghani[2]

[1] Water Resources Engineering Department, Faculty of Engineering, Brawijaya University, Malang - Indonesia
[2] Faculty of Civil Engineering and Earth Resources, University Malaysia Pahang, Pahang - Malaysia
Corresponding author: bambang.winarta@ub.ac.id bwinarta@gmail.com

Abstract. On January 5, 2015, the National Security Council (NSC) confirmed the massive flood that hit Kelantan was the worst in the history of the state. According to the council's report, the water level of Kelantan River at Tambatan Diraja which has a danger level of 25 meters, reached 34.17 meters. The Kelantan River basin is located in the north eastern part of Peninsular Malaysia between latitudes 4° 40' and 6° 12' North, and longitudes 10° 20' and 102° 20' East. The river is about 248 km long and drains an area of 13,100 km^2. It divides into the Galas and Lebir Rivers near Kuala Krai, about 100 km from the river mouth. The Lebir River itself has catchments area of 2430 km^2. This current paper investigates a calibration and confirmation method of hydrologic model using HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) applied in Lebir River. General speaking, the degree of confidence of hydrologic models prediction will normally depend on how well the model can replicate and imitate the observations recorded data. The stream flow data used in this analysis is obtained from station 5222452 at Kg. Tualang with a duration period from years 2004–2014. The results of investigation revealed that the observed and simulated discharge hydrographs in the calibration and confirmation exercises were reasonably close.
Keywords: rainfall runoff model, HEC-HMS, calibration, confirmation

1. Introduction

Hydrological models are used as an essential concern for decision making on water resources engineering and management such as flood mitigation scenarios, hydroelectric power, agriculture development, and water supply–demand analysis. It allows predicting the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practices. The HEC HMS is widely used watershed model to simulate rainfall runoff process.

Several studies have been conducted using the HEC-HMS model in different regions under different soil type and climatic conditions. This hydrologic model has been used for both single event and continuous hydrological modeling in Monalack watershed in west Michigan [1]. HEC-HMS model has been also used to simulate rainfall-runoff process with geo-informatics and atmospheric models for flood forecasting and early warnings in different regions of the world [2-8]. The model gives a good result in predicting watershed response in event based and continuous simulation as well as simulating various scenarios in flood forecasting and early warnings.

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Lebir River basin located in Kelantan State of Malaysia and it is upstream part of Kelatan River that almost every year becomes trending topic in Malaysia in term of flood disaster (Figure 1). It has an approximately 2430km^2 of catchment area. In this river basin, some of meteorological stations have been installed. Due to these reasons, this river basin will be right place to examine the capability of HEC-HMS in developing suitable rainfall runoff model. Then, the calibrated and confirmed rainfall runoff model will be very useful in correlation with integrated watershed management policy.

Figure 1. The location of study: Lebir River basin

2. HEC-HMS Model Set-up of Lebir River

One of the most important steps in hydrological model is constructing of model scheme, it represents of a watershed physically. All hydrologic elements such as: sub-basin, reach, junction, reservoir, diversion, source, sink are connected in a dendritic and orderly network. Then, simulation of runoff process is computed from upstream elements through to downstream outlet. Lebir River was divided in to 38 sub-basins with 41 junctions; one of junctions was a point to compare the result of simulation and observation. This check point is located at Kg. Tualang with meteorological station number 5222452. The hydrological model scheme is displayed in Figure 2.

2.1 Calibration Procedure

In order to calibrate HEC HMS model, a systematic process of adjusting model parameter values is needed until simulation results match acceptably the observed data. The calibration process finds the optimal parameter values that minimize the gap between recorded data and model result. Some strategies and new approaches for rainfall runoff model calibration have been proposed by some researchers [9-11].

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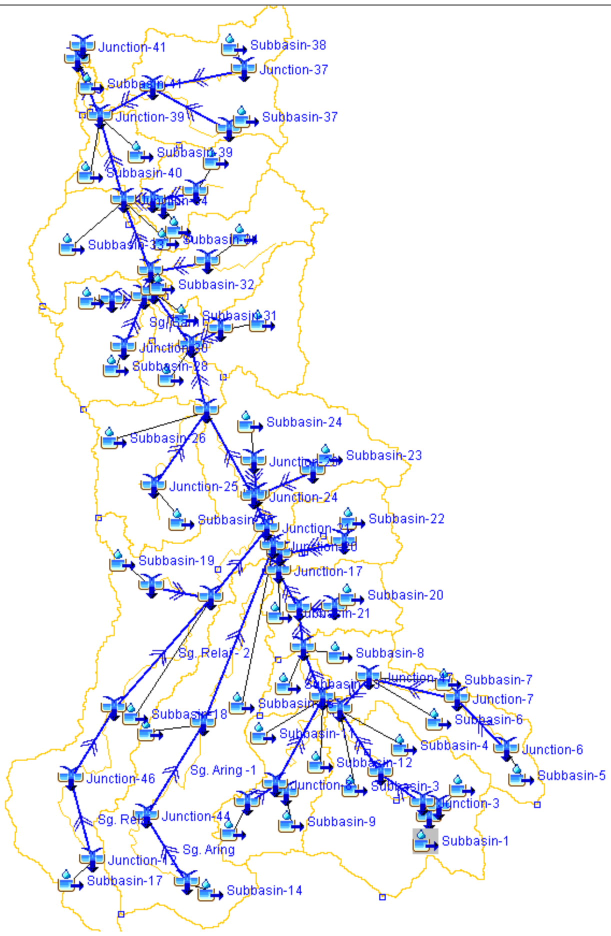

Figure 2. Hydrological model scheme of Lebir River

2.1.1 Clark Unit Hydrograph

A movement of water through the catchment due to gravitational force can be described by time area curve [12]. This method is bounded by the time of concentration (T_c). A multiple linear regression program has been proposed to determine the mathematical relationship of T_c and storage coefficient (R) with catchment area characteristics such as: area, slope and length of mainstream [13]. Around 43 catchment areas of Peninsular Malaysia have been involved to find the equation of T_c and R in correlation with catchment area characteristics and the equations to calculate both parameters are written as below.

$$T_c = 2.32 A^{-0.1188} L^{0.9573} S^{-0.5074} \quad (1)$$

$$R = 2.976 A^{-0.1943} L^{0.9995} S^{-0.4588} \quad (2)$$

where A = catchment area in km^2; L = main stream length in km; S = weighted slope of main stream in m/km.

$$S = \left[\frac{\sum I_i \sqrt{S_i}}{\sum I_i} \right]^2 \quad (3)$$

where I_i is incremental stream length and S_i is incremental slope

The other parameter required as an input in HEC HMS model is base flow, the equation to determine this parameter have been proposed by Dept. of Irrigation and Drainage [14].

$$Q_B = 0.11A^{0.85889} \tag{4}$$

where Q_B is base flow (m^3/s) and A is catchment area (km^2)

2.1.2 Calibration Results

Due to flood event mostly occurred on December, calibration exercises of hydrological model were focused on that month and then, the calibrated model was applied to the other months. Point A in Figure 3 is a location where stream flow gauge installed.

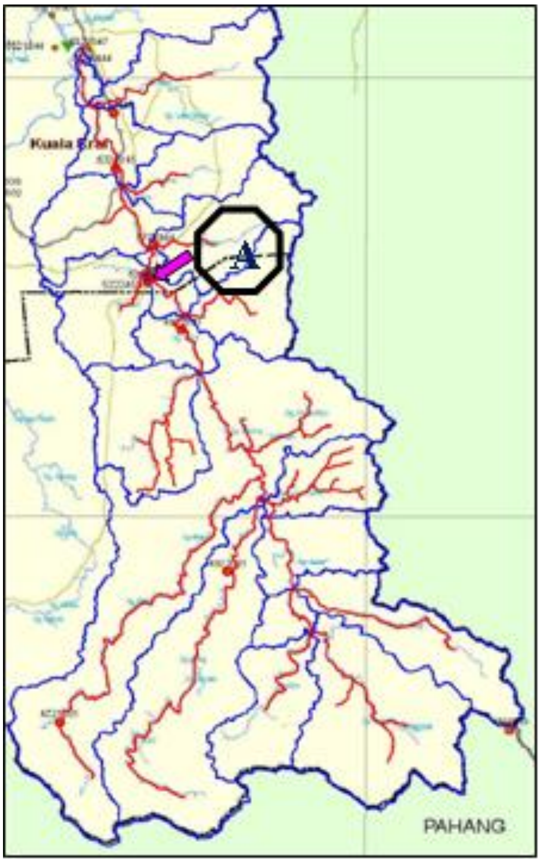

Figure 3. Stream flow gauge in Lebir River

From Figures 4 and 5 show the comparison between observed and modeled flow hydrograph on December 2006 and 2008, it can be seen clearly that hydrological model developed here can predict well flow hydrograph with the values of Root Means Square Error (*RMSE*) = 49.26 m^3/s; Standard Deviation = 228.71 m^3/s for December 2006 and 64.16 m^3/s; Standard Deviation (*SD*) = 169.20 m^3/s for December 2008. When *RMSE* values less than half the standard deviation of the observed (measured) data might be considered low and indicative of a good model prediction [15]. The value of Nash–Sutcliffe efficiency coefficient (NSE) ranges between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Then, the coefficient of determination, R^2, typically is considered acceptable when the value of $R^2 > 0.5$ [16; 17]. The NSE and R^2 value are 0.952; 0.983 for December 2006 and 0.855; 0.935 for December 2008. It can be concluded that HEC HMS can imitate flow hydrograph properly for Lebir River basin.

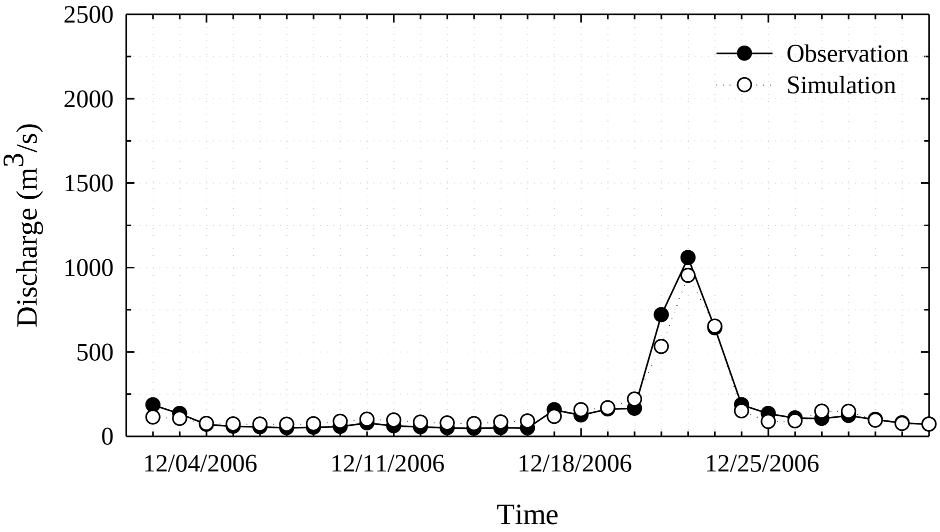

Figure 4. Observed and simulated flow hydrographs on December 2006

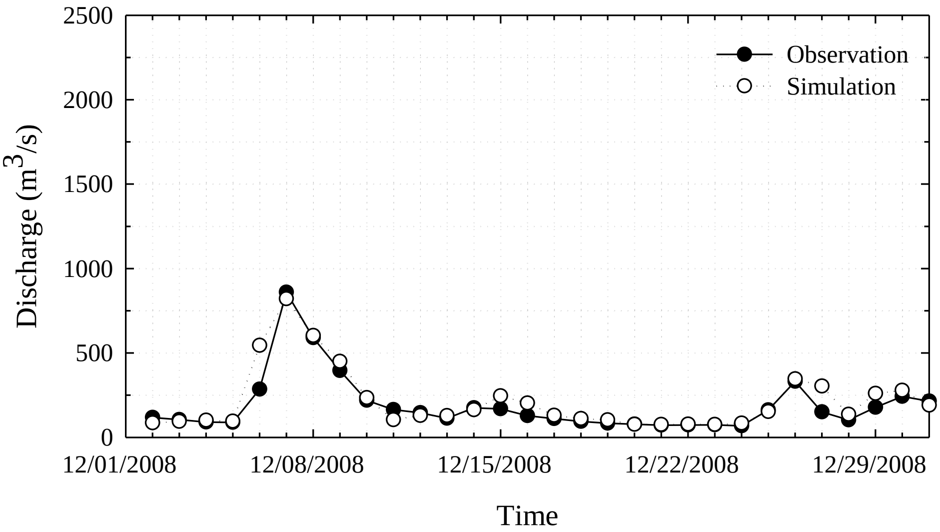

Figure 5. Observed and simulated flow hydrographs on December 2008

2.2 Confirmation Results

The next step after model calibration is testing model ability to simulate observed data at different time series recording with there is no calibrated model parameter change and the result of computation have to get acceptable accuracy. For confirmation of calibrated model, observed data on December 2011, 2013 and November 2013 were used. Figures 6, 7 and 8 show the result of hydrological model confirmation; it can be noticed that calibrated hydrological model can generate flow hydrograph quite well for December 2011, December 2013 and November 2013. The value of some performance indicators are summarized in Table 1. It can be concluded also that the result of confirmation exercises fulfill acceptable level of performance.

Table 1. Performance indicator of HEC HMS model confirmation

Month	Year	Performance Indicators			
		RMSE **(m^3/s)**	***SD*** **(m^3/s)**	***NSE***	R^2
December	2011	89.46	180.99	0.81	0.90
December	2013	214.08	597.91	0.90	0.95
November	2013	24.40	54.51	0.87	0.93

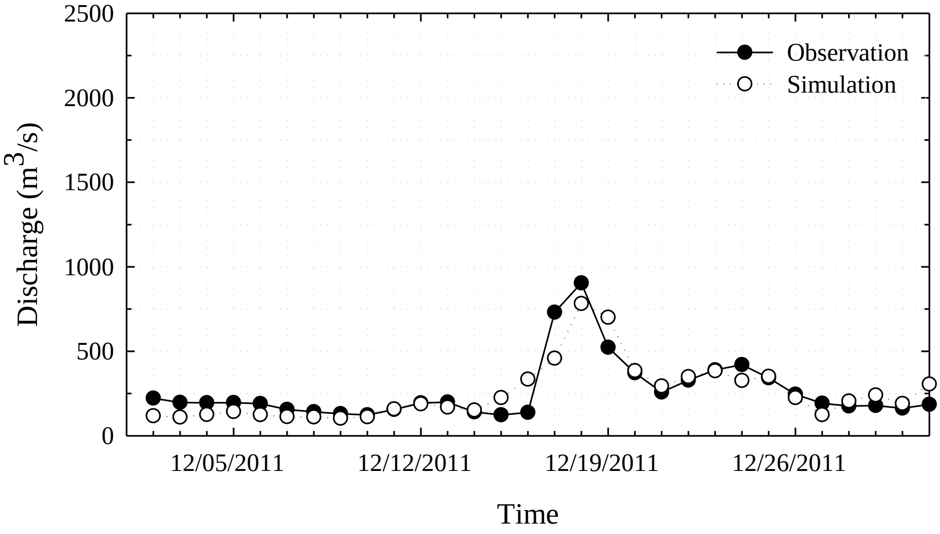

Figure 6. Observed and simulated flow hydrographs on December 2011

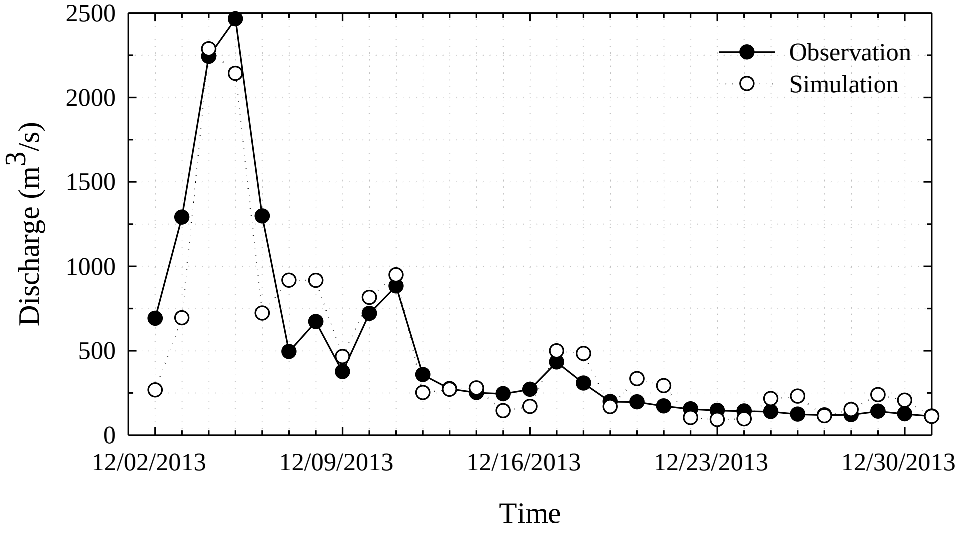

Figure 7. Observed and simulated flow hydrographs on December 2013

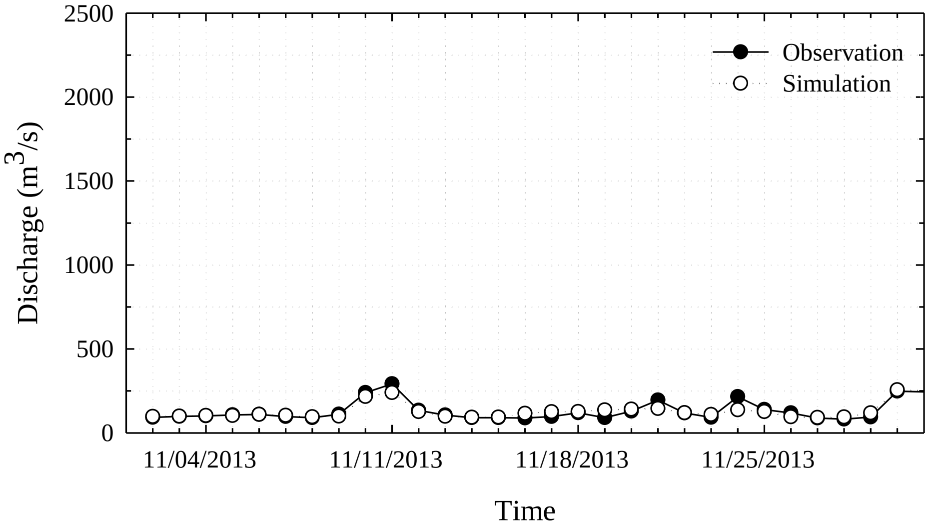

Figure 8. Observed and simulated flow hydrographs on November 2011

3. Conclusions

The HEC-HMS 3.4 computer model can be reliably used to simulate Lebir River flows with calibration and confirmation exercises. The Clark unit hydrograph method has been used to replicate rainfall runoff process, and the result shows reasonably close between recorded data and simulated. The calibrated model can be used to predict flood hydrograph of Lebir River basin that contribute to Kelantan River. The next study will be developing rainfall runoff model for Galas River basin, when all basins of Kelantan River have been developed and modeled well, it can be applied to construct early warning system.

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